CLAIMS

What is claimed is:

1. A method for making a ferritic stainless steel article having an oxidation resistant surface, the method comprising:

providing a ferritic stainless steel comprising aluminum, at least one rare earth metal and 16 to less than 30 weight percent chromium, wherein the total weight of rare earth metals is greater than 0.02 weight percent; and

modifying at least one surface of the ferritic stainless steel so that, when subjected to an oxidizing atmosphere at high temperature, the modified surface develops an electrically conductive, aluminum-rich, oxidation resistant oxide scale comprising chromium and iron and a having a hematite structure differing from Fe_2O_3, alpha Cr_2O_3 and alpha Al_2O_3.

2. The method of claim 1, wherein lattice parameters a_o and c_o of the oxide scale differ from a_o and c_o of Fe_2O_3, alpha Cr_2O_3 and alpha Al_2O_3.

3. The method of claim 1, wherein the at least one modified surface develops the oxide scale when heated in an oxidizing atmosphere at a temperature in the range of 750°C to 850°C.

4. The method of claim 1, wherein the at least one modified surface develops the oxide scale when heated in an oxidizing atmosphere for at least 100 hours at a temperature in the range of 750°C to 850°C.

5. The method of claim 1, wherein the oxide scale is characterized by lattice parameters a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to 13.75 Å.

6. The method of claim 1, wherein the oxide scale is characterized by nominal lattice parameters a_o = 4.98 Å and c_o = 13.57 Å.

7. The method of claim 1, wherein modifying the at least one surface comprises electrochemically modifying the at least one surface.

8. The method of claim 6, wherein electrochemically modifying the at least one surface comprises electropolishing the at least one surface.

9. The method of claim 1, wherein the modified surface develops the oxide scale when heated in an oxidizing atmosphere for at least 100 hours at a temperature in the range of 750°C to 850°C, and wherein the oxide scale is characterized by a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to 13.75 Å.

10. A method for making a ferritic stainless steel article having at least one oxidation resistant surface, the method comprising:

providing a ferritic stainless steel comprising aluminum, at least one rare earth metal and 16 to less than 30 weight percent chromium, wherein the total weight of rare earth metals is greater than 0.02 weight percent; and

modifying at least one surface of the ferritic stainless steel so that the modified surface develops an aluminum-rich oxide scale when heated in an oxidizing atmosphere for at least 100 hours at a temperature in the range of 750°C to 850°C, the oxide scale comprising iron and chromium and having a hematite structure, a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to 13.75 Å.

11. A method for making a ferritic stainless steel article having an oxidation resistant surface, the method comprising:

providing a ferritic stainless steel comprising aluminum, at least one rare earth metal and 16 to less than 30 weight percent chromium, wherein the total weight of rare earth metals is greater than 0.02 weight percent; and

electrochemically modifying at least one surface of the ferritic stainless steel.

12. The method of claim 11, wherein electrochemically modifying the at least one surface comprises electropolishing the at least one surface.

13. The method of claim 12, wherein the at least one electropolished surface develops an aluminum-rich oxide scale comprising iron and chromium and having a hematite structure, a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to

13.75 Å, when heated in an oxidizing atmosphere for at least 100 hours at a temperature in the range of 750°C to 850°C.

14.. The method of claim 12, wherein the ferritic stainless steel comprises 16 up to 19 weight percent chromium.

15. The method of claim 12, wherein the ferritic stainless steel comprises at least 0.2 weight percent aluminum.

16. The method of claim 12, wherein the ferritic stainless steel comprises 0.2 up to 1.0 weight percent aluminum.

17. The method of claim 12, wherein the total weight of rare earth metals in the ferritic stainless steel is greater than 0.02 up to 1.0 weight percent.

18. The method of claim 12, wherein the ferritic stainless steel comprises at least one rare earth metal selected from cerium, lanthanum, yttrium and hafnium.

19. The method of claim 18, wherein the total weight of rare earth metals in the ferritic stainless steel is greater than 0.02 up to 1.0 weight percent.

20. The method of claim 12, wherein the ferritic stainless steel comprises, in weight percent, 18 up to 22 chromium, 0.4 to 0.8 aluminum and 0.02 to 0.2 REM.

21. The method of claim 12, wherein the ferritic stainless steel further comprises, in weight percent, up to 3 nickel, up to 3 manganese, up to 0.7 silicon, up to 0.07 nitrogen, up to 0.07 carbon and up to 0.5 titanium.

22. The method of claim 12, wherein the ferritic stainless steel comprises, in weight percent, about 22 chromium, about 0.6 aluminum, cerium and lanthanum, wherein the sum of the weights of cerium and lanthanum is up to about 0.10.

23. The method of claim 12, wherein the article is selected from the group consisting of a plate, a sheet, a strip, a foil, a bar, a fuel cell interconnect, high-temperature manufacturing equipment, high-temperature handling equipment, calcining equipment, glass making equipment, glass handling equipment, heat exchanger components.

24. The method of claim 12, wherein the article is a fuel cell interconnect and the ferritic stainless steel comprises 16 to less than 30 weight percent chromium, at least 0.2 weight percent aluminum, and at least one rare earth metal, wherein the total weight of rare earth metals is greater than 0.02 up to 1.0 weight percent.

25. The method of claim 12, wherein electropolishing at the least one surface of the article comprises:

placing the at least one surface of the article in a bath containing an electropolishing solution and a cathode; and

passing a current between the article and the cathode so that material is removed from the at least one surface, thereby reducing surface roughness of the surface.

26. The method of claim 12, wherein electropolishing the at least one surface improves resistance of the at least one surface to oxidation when subjected to a temperature and an atmosphere characteristic of operating conditions within a solid oxide fuel cell.

27. The method of claim 12, wherein the at least one electropolished surface has oxidation resistance in air at 750°C characterized by a log k_p less than -9.1 g^2/cm^4h.

28. The method of claim 12, wherein the at least one electropolished surface has oxidation resistance in air at 850°C characterized by a log k_p less than -8.5 g^2/cm^4h.

29. A method of improving high temperature oxidation resistance of a ferritic stainless steel article comprising 16 to less than 30 weight percent chromium, at least 0.2 weight percent aluminum, and at least one rare earth metal, wherein the total weight of rare earth metals is greater than 0.02 up to 1.0 weight percent, the method comprising electrochemically modifying at least one surface of the article, wherein the at least one electrochemically modified surface develops an aluminum-rich oxide layer having a hematite structure when subjected to an atmosphere and a temperature

characteristic of conditions to which a solid oxide fuel cell interconnect is subjected during fuel cell operation.

30. The method of claim 29, wherein electrochemically modifying at least one surface of the article comprises electropolishing the at least one surface.

31. The method of claim 29, wherein the ferritic stainless steel comprises 16 up to 19 weight percent chromium.

32. The method of claim 29, wherein the ferritic stainless steel comprises 0.2 up to 1.0 weight percent aluminum.

33. The method of claim 29, wherein the ferritic stainless steel comprises at least one rare earth metal selected from cerium, lanthanum, yttrium and hafnium.

34. The method of claim 29, wherein the ferritic stainless steel comprises, in weight percent, 18 up to 22 chromium, 0.4 to 0.8 aluminum and 0.02 to 0.2 rare earth metals.

35. A method of making a solid oxide fuel cell, the method comprising:

providing at least one interconnect, wherein the interconnect comprises a ferritic stainless steel including aluminum, at least one rare earth metal and 16 to less than 30 weight percent chromium, wherein the total weight of rare earth metals is greater than 0.02 weight percent, and wherein the interconnect further comprises at least one

modified surface that, when subjected to an oxidizing atmosphere at high temperature, develops an electrically conductive, aluminum-rich, oxidation resistant oxide scale comprising chromium and iron and a having a hematite structure differing from Fe_2O_3, alpha Cr_2O_3 and alpha Al_2O_3; and

assembling the solid oxide fuel cell from the at least one interconnect and additional components comprising at least one anode, at least one cathode, and at least one electrolyte.

36. The method of claim 35, wherein lattice parameters a_o and c_o of the oxide scale differ from a_o and c_o of Fe_2O_3, alpha Cr_2O_3 and alpha Al_2O_3.

37. The method of claim 35, wherein the modified surface develops the oxide scale when heated in an oxidizing atmosphere at a temperature in the range of 750°C to 850°C.

38. The method of claim 35, wherein the modified surface develops the oxide scale when heated in an oxidizing atmosphere for at least 100 hours at a temperature in the range of 750°C to 850°C.

39. The method of claim 35, wherein the oxide scale is characterized by a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to 13.75 Å.

40. The method of claim 35, wherein the oxide scale is characterized by nominal lattice parameters $a_o = 4.98$ Å and $c_o = 13.57$ Å.

41.. A method of making a solid oxide fuel cell, the method comprising:

providing at least one interconnect, wherein the interconnect comprises a ferritic stainless steel including aluminum, at least one rare earth metal and 16 to less than 30 weight percent chromium, wherein the total weight of rare earth metals is greater than 0.02 weight percent, and wherein the interconnect includes at least one electrochemically modified surface; and

assembling the solid oxide fuel cell from the at least one interconnect and additional components comprising at least one anode, at least one cathode, and at least one electrolyte.

42. The method of claim 41, wherein the at least one electrochemically modified surface is at least one electropolished surface.

43. The method of claim 41, wherein the at least one electropolished surface develops an aluminum-rich oxide scale comprising iron and chromium and having a hematite structure, a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to 13.75 Å, when heated in an oxidizing atmosphere for at least 100 hours at a temperature in the range of 750°C to 850°C.

44. The method of claim 43, wherein the oxide scale is characterized by nominal lattice parameters a_o = 4.98 Å and c_o = 13.57 Å.

45. The method of claim 41, wherein the ferritic stainless steel includes 16 up to 19 weight percent chromium.

46. The method of claim 41, wherein the ferritic stainless steel comprises 0.2 up to 1.0 weight percent aluminum.

47. The method of claim 41, wherein the ferritic stainless steel comprises, in weight percent, 18 up to 22 chromium, 0.4 to 0.8 aluminum and 0.02 to 0.2 rare earth metals.

48. The method of claim 41, wherein the solid oxide fuel cell is a planar solid oxide fuel cell.

49. A ferritic stainless steel comprising aluminum, at least one rare earth metal and 16 to less than 30 weight percent chromium, wherein the total weight of rare earth metals is greater than 0.02 weight percent, the ferritic stainless steel further comprising at least one modified surface, wherein when subjected to an oxidizing atmosphere at high temperature, the at least one modified surface develops an electrically conductive, aluminum-rich, oxidation resistant oxide scale comprising chromium and iron and a having a hematite structure differing from Fe_2O_3, alpha Cr_2O_3 and alpha Al_2O_3.

50. The ferritic stainless steel of claim 49, wherein lattice parameters a_o and c_o of the oxide scale differ from a_o and c_o of Fe_2O_3, alpha Cr_2O_3 and alpha Al_2O_3.

51. The ferritic stainless steel of claim 49, wherein the at least one modified surface develops the oxide scale when heated in an oxidizing atmosphere at a temperature in the range of 750°C to 850°C.

52. The ferritic stainless steel of claim 49, wherein the at least one modified surface develops the oxide scale when heated in an oxidizing atmosphere for at least 100 hours at a temperature in the range of 750°C to 850°C.

53. The ferritic stainless steel of claim 49, wherein the oxide scale is characterized by a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to 13.75 Å.

54. The ferritic stainless steel of claim 49, wherein the oxide scale is characterized by nominal lattice parameters a_o = 4.98 Å and c_o = 13.57 Å.

55. The ferritic stainless steel of claim 49, wherein the at least one modified surface is at least one electrochemically modified surface.

56. The ferritic stainless steel of claim 51, wherein the at least one electrochemically modified surface is at least one electropolished surface.

57. The ferritic stainless steel of claim 56, wherein the at least one electropolished surface develops the oxide scale when heated in an oxidizing atmosphere for at least 100 hours at a temperature in the range of 750°C to 850°C, and wherein the oxide scale is characterized by a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to 13.75 Å.

58. The ferritic stainless steel of claims 57, wherein the oxide scale is characterized by nominal lattice parameters a_o = 4.98 Å and c_o = 13.57 Å.

59. A ferritic stainless steel comprising aluminum, at least one rare earth metal and 16 to less than 30 weight percent chromium, wherein the total weight of rare earth metals is greater than 0.02 weight percent, and wherein the ferritic stainless steel further comprises at least one electrochemically modified surface.

60. The ferritic stainless steel of claim 59, wherein the at least one electrochemically modified surface is at least one electropolished surface.

61. The ferritic stainless steel of claim 60, wherein the at least one electropolished surface develops an aluminum-rich oxide scale including iron and chromium and having a hematite structure, a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to 13.75 Å when heated for at least 100 hours at 750°C to 850°C in an oxidizing atmosphere.

62. The ferritic stainless steel of claim 60, wherein the oxide scale is characterized by nominal lattice parameters a_o = 4.98 Å and c_o = 13.57 Å.

63. The ferritic stainless steel of claim 59, comprising 16 up to 19 weight percent chromium.

64. The ferritic stainless steel of claim 59, comprising at least 0.2 weight percent aluminum.

65. The ferritic stainless steel of claim 59, comprising 0.2 up to 1.0 weight percent aluminum.

66. The ferritic stainless steel of claim 59, wherein the total weight of rare earth metals in the ferritic stainless steel is greater than 0.02 up to 1.0 weight percent.

67. The ferritic stainless steel of claim 59, wherein the ferritic stainless steel comprises at least one rare earth metal selected from cerium, lanthanum, yttrium and hafnium.

68. The ferritic stainless steel of claim 59, wherein the total weight of rare earth metals in the ferritic stainless steel is greater than 0.02 up to 1.0 weight percent.

69. The ferritic stainless steel of claim 59 comprising, in weight percent, 18 up to 22 chromium, 0.4 to 0.8 aluminum and 0.02 to 0.2 rare earth metals.

70. The ferritic stainless steel of claim 59, further comprising, in weight percent, up to 3 nickel, up to 3 manganese, up to 0.7 silicon, up to 0.07 nitrogen, up to 0.07 carbon and up to 0.5 titanium.

71. The ferritic stainless steel of claim 59, comprising, in weight percentages, about 22 chromium and about 0.6 aluminum, cerium and lanthanum, wherein the sum of the weights of cerium and lanthanum is up to about 0.10.

72. The ferritic stainless steel of claim 59, comprising 16 to less than 30 weight percent chromium, at least 0.2 weight percent aluminum, and at least one rare earth metal, wherein the total weight of rare earth metals is greater than 0.02 up to 1.0 weight percent.

73. The ferritic stainless steel of claim 59, wherein the at least one electrochemically modified surface exhibits improved resistance to oxidation when subjected to atmosphere and temperature conditions characteristic of the operating conditions in a solid oxide fuel cell.

74. The ferritic stainless steel of claim 59, wherein the at least one electropolished surface has oxidation resistance in air at about 750°C characterized by log k_p less than -9.1 g^2/cm^4h.

75. The ferritic stainless steel of claim 59, wherein the at least one electropolished surface has oxidation resistance in air at about 850°C characterized by log k_p less than -8.5 g^2/cm^4h.

76. A ferritic stainless steel comprising 16 to less than 30 weight percent chromium, at least 0.2 weight percent aluminum, and at least one rare earth metal, wherein the total weight of rare earth metals is greater than 0.02 up to 1.0 weight percent, the ferritic stainless steel further comprising at least one oxidation resistant electropolished surface that develops an aluminum-rich oxide layer when heated in air at a temperature in the range of 750°C to 850°C.

77. An article of manufacture comprising a ferritic stainless steel including aluminum, at least one rare earth metal and 16 to less than 30 weight percent chromium, wherein the total weight of rare earth metals is greater than 0.02 weight percent, the ferritic stainless steel further comprising at least one modified surface, wherein when subjected to an oxidizing atmosphere at high temperature, the modified surface develops an electrically conductive, aluminum-rich, oxidation resistant oxide scale comprising chromium and iron and a having a hematite structure differing from Fe_2O_3, alpha Cr_2O_3 and alpha Al_2O_3.

78. The article of manufacture of claim 77, wherein lattice parameters a_o and c_o of the oxide scale differ from a_o and c_o of Fe_2O_3, alpha Cr_2O_3 and alpha Al_2O_3.

79. The article of manufacture of claim 77, wherein the oxide scale is characterized by a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to 13.75 Å.

80. The article of manufacture of claim 77, wherein the oxide scale is characterized by nominal lattice parameters a_o = 4.98 Å and c_o = 13.57 Å.

81. The article of manufacture of claim 77, wherein the modified surface is an electropolished surface.

82. An article of manufacture comprising a ferritic stainless steel including aluminum, at least one rare earth metal and 16 to less than 30 weight percent chromium, wherein the total weight of rare earth metals is greater than 0.02 weight percent, and further including at least one electrochemically modified surface.

83. The article of manufacture of claim 82, wherein the at least one electrochemically modified surface is at least one electropolished surface.

84. The article of manufacture of claim 82, wherein the ferritic stainless steel comprises 16 to less than 30 weight percent chromium, at least 0.2 weight percent

aluminum, and at least one rare earth metal, wherein the total weight of rare earth metals is greater than 0.02 up to 1.0 weight percent.

85. The article of manufacture of claim 82, wherein the ferritic stainless steel comprises, in weight percent, 18 up to 22 chromium, 0.4 to 0.8 aluminum and 0.02 to 0.2 rare earth metals.

86. The article of manufacture of claim 82, wherein the at least one electrochemically modified surface develops an aluminum-rich oxide scale including iron and chromium and having a hematite structure, a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to 13.75 Å when heated for at least 100 hours at 750°C to 850°C in an oxidizing atmosphere.

87. The article of manufacture of any of claims 77 and ~~82,~~ 82 wherein the article of manufacture is selected from a fuel cell, a solid oxide fuel cell, a planar solid oxide fuel cell, a fuel cell interconnect, a high-temperature manufacturing apparatus, a high-temperature handling apparatus, a calcining apparatus, a glass making apparatus, a glass handling apparatus and a heat exchanger component.

88. A fuel cell comprising:

an anode;

a cathode;

a solid electrolyte intermediate the anode and the cathode; and

an interconnect comprising a ferritic stainless steel including 16 to less than 30 weight percent chromium, at least 0.2 weight percent aluminum, and at least one rare earth metal, wherein the total weight of rare earth metals is greater than 0.02 up to 1.0 weight percent, the ferritic stainless steel further comprising at least one modified surface, wherein when subjected to an oxidizing atmosphere at high temperature, the modified surface develops an electrically conductive, aluminum-rich, oxidation resistant oxide scale comprising chromium and iron and a having a hematite structure differing from Fe_2O_3, alpha Cr_2O_3 and alpha Al_2O_3.

89. The fuel cell of claim 88, wherein lattice parameters a_o and c_o of the oxide scale differ from a_o and c_o of Fe_2O_3, alpha Cr_2O_3 and alpha Al_2O_3.

90. The fuel cell of claim 88, wherein the at least one modified surface is an electrochemically modified surface.

91. A fuel cell comprising:

an anode;

a cathode;

a solid electrolyte intermediate the anode and the cathode; and

an interconnect comprising a ferritic stainless steel including aluminum, at least one rare earth metal and 16 to less than 30 weight percent chromium, wherein the total weight of rare earth metals is greater than 0.02 weight percent, and wherein the ferritic stainless steel further comprises at least one electrochemically modified surface.

92. The fuel cell of claim 91, wherein the at least one electrochemically modified surface is at least one electropolished surface.

93. The fuel cell of claim 91, wherein the ferritic stainless steel develops an aluminum-rich oxide scale including iron and chromium and having a hematite structure, a_o in the range of 4.95 to 5.04 Å and c_o in the range of 13.58 to 13.75 Å when heated for at least 100 hours at 750°C to 850°C in an oxidizing atmosphere.

94. The fuel cell of claim 93, wherein the oxide scale is characterized by nominal lattice parameters a_o = 4.98 Å and c_o = 13.57 Å.

95. The fuel cell of claim 91, wherein the ferritic stainless steel comprises 16 to less than 30 weight percent chromium, at least 0.2 weight percent aluminum, and at least one rare earth metal, wherein the total weight of rare earth metals is greater than 0.02 up to 1.0 weight percent.

96. The fuel cell of claim 91, wherein the ferritic stainless steel comprises, in weight percent, 18 up to 22 chromium, 0.4 to 0.8 aluminum and 0.02 to 0.2 rare earth metals.

97. The fuel cell of claim 91, wherein the fuel cell is selected from a solid oxide fuel cell and a planar solid oxide fuel cell.

98. The fuel cell of claim 91, wherein the fuel cell is fuel cell stack comprising a plurality of cells, each cell comprising an anode, a cathode an electrolyte, and an interconnect, the interconnects electrically connecting the plurality of cells in series.